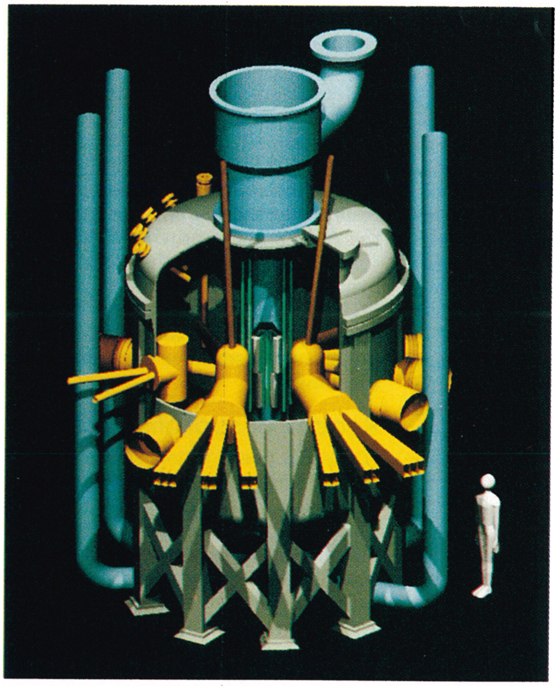
THE ADVANCED NEUTRON SOURCE KNOCKS AT THE DOOR OF CONGRESS

In the wake of the cancellation of the $11 billion Superconducting Super Collider, another big-ticket physics facility is seeking its fortunes with Congress. The supplicant is the Advanced Neutron Source, a $2.9 billion research reactor designed at Oak Ridge National Laboratory to provide at least five times the neutron flux of any existing facility and support up to 1000 users per year, conducting experiments in material, biological, condensed-matter and chemical physics. The 1994 Nobel Prize in Physics was just awarded for the type of studies that would be done at the ANS: The Royal Swedish Academy of Sciences gave the prize to Bertram N. Brockhouse of McMaster University in Hamilton, Ontario, and Clifford Shull of MIT for "pioneering contributions to the development of neutron-scattering techniques for studies of condensed matter."

Like the SSC, the ANS faces a tough fight in Congress. Its mission is directly linked to that "in" phrase, "industrial competitiveness," but its pricetag challenges the tight Federal budget. Even as a separate line item, the facility could impact the funding available for other physics projects. In the next few years DOE is certain to advance the cause of other facilities, such as the National Ignition Facility, the International Thermonuclear Experimental Reactor and ITER's precursor, the Tokomak Physics Experiment. In the FY95 budget Congress granted the project $21 million for design work but failed to allocate the requested construction funds (see PHYSICS TODAY, October 1994, page 61).

The ANS is additionally beset by concern over nuclear weapons proliferation: The original design called for the ANS to be fueled with weapons-grade, highly enriched uranium. Recently the ANS team came up with a design that uses a lower level of enrichment.



ANS core and reactor vessel are shown in this figure, next to a six-foot-tall mannequin. Two annular elements (silvery blue) at the reactor's center comprise the core. (A modification to accommodate fuel with lower enrichment would add a third such element.) Vertical blue pipes are for isotope production and other experiments. Yellow pipes extending radially are neutron beams for scattering experiments. (Courtesy of Oak Ridge.)

The mission of ANS

The Advanced Neutron Source would have basically three types of products: a neutron beam for scattering studies; energetic neutrons and gamma rays for materials irradiation; and a wide variety of neutron-rich isotopes. (See the figure above.) Colin West is the director of the ANS project, John Hayter is its scientific director and Bill Appleton is associate laboratory director for ANS at Oak Ridge.

The heaviest use of the proposed reactor is expected to be for neutron scattering, which nicely complements x-ray scattering in the study of materials (see the special issue on neutron scattering in PHYSICS TODAY, January, 1985). Being uncharged, neutrons can penetrate deeply to interact with the nuclei of the target material. Their magnetic moments can couple to those of the unpaired electrons in the target atoms. And the neutrons can be polarized to give detailed information about the magnetic structure of the sample. With neutrons, you can "see" the location of light atoms such as hydrogen and carbon, which are hard to pinpoint with x rays. In organic chemistry and biology this identification helps complete the crystallographic determination of a substance. In studies of complex polymer fluids and biological materials, one can label a particular structural unit by replacing some of its hydrogen atoms with deuterons.

Neutron beams can come either from reactors, in which neutrons are by-products of the fission reaction, or from spallation sources, which produce neutrons by colliding high-energy protons from an accelerator with a metallic target. Although there is considerable overlap in capabilities between the two types of facilities, they differ in the kinds of experiments they best support. For neutron-scattering experiments, reactors are generally better in providing neutrons at the low-end of the energy spectrum (1–100 meV), while spallation sources are more desirable for applications at the more energetic end (0.1–10 eV). Moreover, spallation sources are usually pulsed so they are more suitable, say, for time-of-flight measurements than for isotope production.

Researchers, engineers and physicians who rely on neutron sources feel that the facilities available to them in the US are falling far behind those in Europe. The two research reactors in the US with the highest neutron flux were built at Oak Ridge and Brookhaven National Laboratory in 1966 and 1965, respectively. Each produces about 10^{19} neutrons/m^2-sec. The US also has two spallation sources: the Intense Pulsed Neutron Source built at Argonne National Laboratory in 1981 and a neutron source (known as LANSCE) constructed at the Los Alamos Meson Physics Facility in 1985. The one new facility built for neutron research in the US in the last five years is the Cold Neutron Research Facility fed by an existing reactor at the National Institute of Standards and Technology in Gaithersburg, Maryland (see PHYSICS TODAY, September 1991, page 17).

The premier neutron reactor in Europe, located at the Institut Laue–Langevin in Grenoble, France, has a flux that is not much higher than those available at the Brookhaven and Oak Ridge reactors, but the ILL has been continually upgraded with tailored cold and hot sources and the latest instrumentation. Germany recently upgraded a reactor in Berlin and plans to replace its oldest reactor, located in Munich, with a completely new one. Within the last two years Japan commissioned a new research reactor, called JRR-3, which is sited at the Japan Atomic Energy Research Institute at Tokaimura. These new reactors all have lower fluxes than the ILL.

In 1985 England built a spallation source, Isis, at the Rutherford Appleton Laboratory in Chilton. Its beam power is about twice that of LANSCE, the more powerful of the US spallation sources, and the English facility is better equipped than either of the US sources. Overall, the time-averaged flux from the spallation sources is roughly several orders of magnitude below that of the ILL.

Even as the US has lagged in constructing neutron sources, the need for such sources has accelerated, according to a 1993 report of a panel convened by DOE's Basic Energy Sciences Advisory Committee and headed by Walter Kohn of the University of California, Santa Barbara. As examples of the contributions that neutron physics has made to fundamental science, the panel cites studies of the structure and excitations of high-T_c superconductors, polymer conformations and interactions, structure and dynamics of new-generation catalysts, and structure and phase transformations of buckyballs. On the technical side, the panel points to research on residual stress in metals and ceramics, radiography of aircraft and energy-production components, and near-surface impurities and deposits in semiconductors.

Almost all neutron-scattering research is currently flux-limited. The low neutron currents in turn limit the resolution that can be achieved. Thus the ANS aims to provide at least five times more neutron flux than is now available at the ILL reactor. The higher flux at the ANS will be especially valuable for studies where sample sizes are small or exposure times are limited.

Reactor or spallation source?

If the US needs a new source of neutrons, which type should be built? That was the question that Kohn's panel sought to answer. Their recommendation was to build the ANS now and a complementary 1-MW pulsed spallation source later. One reason to push the ANS ahead of the PSS was that its design work was further along. The panel also felt that the 330-MW ANS would provide better support than would a 1-MW spallation source for isotope production, high-flux engineering and most neutron scattering experiments, especially those in the subthermal regime. To approach the same time-averaged flux as the ANS would require an equally costly 5-MW spallation source, which, in the panel's opinion, is still far off on the technological frontier.

The Kohn panel included researchers involved with both spallation sources and research reactors. David Price, former director of Argonne's IPNS spallation source, told us that while the panel debated the issues vigorously, it unanimously supported its final recommendations.

The Europeans do not plan another reactor source but currently hope to build a 5-MW spallation source. If all the proposed neutron sources were actually built, one would have a situation that Kohn describes as "doubly complementary": The US would have the premier high-flux reactor and a complementary pulsed spallation source, while Europe would boast the top spallation source and a complementary reactor, the ILL.

The baseline design for the ANS is a 330-MW nuclear reactor, which aims at a peak flux about seven times that of the ILL, or 7.33×10^{19} n/m^2-sec. That flux level lies in the middle of the range, 5–10 times the flux of the ILL, which was recommended by a 1984 panel convened by the National Academy of Sciences to review major facilities for materials research. The basic technology underlying the ANS is not new, but the reactor would operate with some of its parameters close to their extreme values. Robert Bari of Brookhaven likens the ANS to a racing car, which requires high-test fuel. The power density would be higher than any reactor to date, and designers have had to pay special attention to the shape of the fuel and the heat transfer capabilities of the reactor.

Questions naturally arise over the accuracy of the estimated cost, especially in view of the large cost overruns experienced by some commercial nuclear plants in the past. West, the ANS project director, defends his team's estimated cost, pointing out that it falls within 2% of an independent estimate commissioned by the DOE.

Proliferation concerns

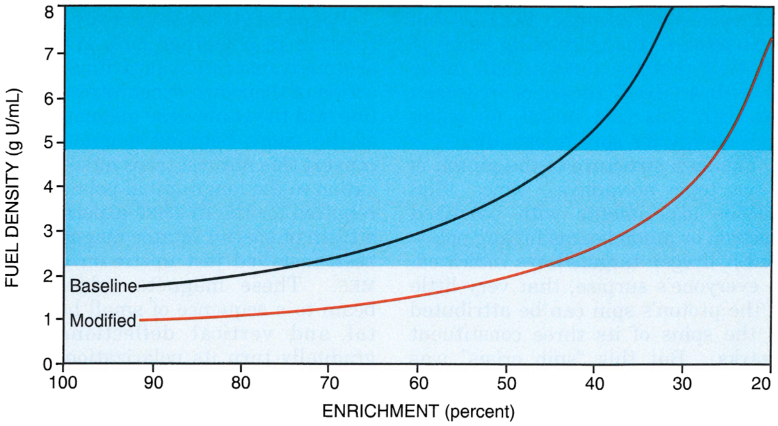
The original design called for uranium that contained 93% of the fissile isotope ^{235}U (natural uranium has only about 0.7% ^{235}U). The core of the ANS would contain 25 kg of such highly enriched uranium and would require refueling every 17 days. A rough estimate of the prompt critical mass needed to make a very crude bomb is 50 kg of highly enriched uranium, or two cores worth.[2] The corresponding masses for 50%, 35% and 20% enrichment are 350 kg, 1 tonne and 6 tonnes, respectively. (One could, of course, make a bomb with less material using more sophisticated techniques.) The ANS would not require the production of new highly enriched uranium; there are already ample quantities in stockpiles of dismantled warheads stored at Oak Ridge.

The use of highly enriched uranium conflicts with US policy aimed at nuclear nonproliferation. The US has been encouraging other nations not to use highly enriched uranium in any new reactors and whenever possible, to convert reactors already so fueled to low-enriched uranium, technically defined as containing 20% ^{235}U. To support this policy, the Reduced Enrichment for Research and Test Reactors program was started in 1978 at Argonne to develop, test and demonstrate a series of low-enriched uranium research reactor fuels, with significantly higher uranium densities to compensate for the lower enrichment. So far nine US research reactors and 15 overseas research reactors have been converted to low-enriched uranium. US policy does not specifically forbid the construction of a domestic reactor that uses highly enriched uranium, but building the ANS as designed, with 93% enriched uranium fuel, would be inconsistent with US policy and would establish a double standard for domestic and foreign research reactors.

Concern over this issue led Congress to request in its FY94 budget that the ANS designers address the enrichment level of its fuel. A team composed of researchers from Brookhaven National Laboratory, Argonne, Oak Ridge and the Idaho National Engineering Laboratory and led by Bari studied the trade-offs among enrichment level, flux, cost, safety and safeguards. There is a limit to increasing the fuel density of the uranium silicide fuel planned for the ANS: Frequently, denser fuels have lower thermal conductivity, leading to higher temperatures in the fuel.

In a draft report issued last January the study group led by Bari stated that one could operate the ANS at the same power level with a 35% enriched fuel but with 20% less flux and $0.4 billion higher costs over the plant lifetime of 40 years. This configuration would require a larger core and higher fuel density (3 g/cc). The study group's overall conclusion was that "although it would be feasible to redesign the Advanced Neutron Source to operate with medium- or low-enriched uranium fuels, such designs would significantly reduce performance and increase cost."

Since the Bari study, Oak Ridge has come up with a design that would allow the ANS to operate at the same power and cost with a lower level of enrichment compared to the baseline design. The figure above shows the trade-off between enrichment level and fuel density for the baseline and for the modified design. In the modified design, which uses a larger core, the flux would be just over five times that of the ILL. The reactor might be fueled with 50% enriched fuel having a material density of 2.2 g/cc, or with 35% enriched fuel at 3.5 g/cc.



Trade-off between enrichment level and fuel density for the ANS. Below 2.2 g/cc, no fuel development is needed; regions of light, medium and dark shading indicate, respectively, small, moderate and high risk of failure. The baseline design features a two-element core. Going to the modified design, with a three-element core, enables one to lower the uranium enrichment level below the planned 93% without going above a fuel density of 3.5 g/cc. Not shown is the decrease in flux level at lower enrichment levels. (Courtesy of Oak Ridge.)

Researchers on nuclear fuels give the 2.2-g/cc density fuel nearly 100% chance of success and the 3.5 g/cc a 95% chance. The larger core gives reactor designers the option to operate at even lower levels of enrichment, perhaps with some reduction in flux, if higher density fuels are developed. It also gives operators a greater margin of safety because of the lower power density.

Switching from 93% to 50% or 35% enrichment lowers the danger of diversion of materials from the reactor, but it does not entirely avoid the conflict with US nonproliferation policy. Oak Ridge is awaiting comments from DOE on its proposed redesign. In the meantime, the lab is proceeding to optimize the design.

—Barbara Goss Levi

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HERA IS NOW RUNNING WITH LONGITUDINALLY POLARIZED POSITRONS

Recently there have been some interesting developments at HERA, the Hadron–Electron Ring Accelerator that wends its circular way for 6 kilometers beneath the streets and parks of Hamburg. Since the fall of 1992 this uniquely asymmetric pair of storage rings has been providing experimenters with collisions between 820-GeV protons and 30-GeV electrons. (See PHYSICS TODAY March 1992, page 21.) Since July, however, HERA has been running with positrons instead of electrons, and will continue to do so at least until the end of 1995. And more importantly, the circulating HERA positron (or electron) beam can now be longitudinally polarized at will. That's an important first: No other electron storage ring has ever achieved longitudinal polarization.

HERMES and the spin crisis

The new HERMES detector, which will join the two original detectors in the beam line this month, will be the first to take advantage of HERA's new polarization capability. To investigate the spin structure of the proton, one wants to collide longitudinally polarized charged leptons (electrons, positrons or muons) with longitudi-